

Standing Stem Persistence in No-tillage Small-Grain Fields

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ABSTRACT

Standing stem residues affect erosion, hydrology, and other processes differently than flat residues, but stem persistence under no-tillage management is not well understood. We developed an equation to predict standing stem number over time, based on precipitation and air temperature. Crops were field-grown winter and spring wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and oat (*Avena sativa* L.) grown near Bushland, TX, on Pullman clay loam (fine, mixed, thermic Torricic Paleustoll). Fallow-period irrigation treatments produced three decomposition environments. Standing stems were counted in flagged quadrats 18, 98, 158, 223, 289, and 379 d after harvest. The daily minimum of precipitation-based moisture or mean air temperature coefficients was accumulated as decomposition days (DD). Standing stem fraction (SF) was predicted assuming $SF = \exp[k(DD - B)]$. The threshold, B , was ≈ 17.5 DD for all crops, and k was -0.284 , -0.176 , -0.169 , and -0.116 for oat, barley, and winter and spring wheat, respectively. Equation evaluation used data from North Dakota, Oregon, and Texas. Stem number prediction tended to be high before the B threshold and low later. Paired t -tests indicated no significant difference between predicted and measured stem fraction of spring wheat or barley. Stem fraction was overestimated by 0.09 for winter wheat averaged across Oregon and Texas data. Use of DDs improved prediction of standing stem persistence across diverse climates. Such information is needed for a wide range of erosion, water balance, and micrometeorological studies. A quantitative index for forces such as strong winds, animal traffic, or blowing precipitation may improve the model.

RESIDUE MANAGEMENT is critical to soil and water conservation. More than 67% of all Conservation

Compliance plans developed for highly erodible crop land in the USA rely on improved residue management to control erosion (SWCS, 1991). Crop residues also affect important surface energy balance and hydrologic processes (Steiner, 1994). However, our understanding of the persistence and distribution of crop residues over time is incomplete.

Standing stems affect erosion and hydrologic processes differently than do flat residues distributed on the soil surface. Standing stems reduce wind speed at the soil surface; initiation of particle movement thereby requires stronger winds (Foster, 1991; Hagen, 1991). Standing stems are particularly effective for soil water storage when snow accounts for a significant proportion of precipitation (Black and Siddoway, 1977). Additionally, standing residues persist longer than flat residues that are in close contact with the soil. Tanaka (1986) reported mass loss of about 0.03 or 0.04% d^{-1} from standing spring wheat or winter wheat stems during prolonged fallow periods. Also, 45% of winter wheat stems remained standing after 426 d of fallow; for spring wheat, 46% of stems remained standing after 638 d of fallow.

Following harvest in a no-tillage system, standing stems persist until the stem base decomposes at or below the soil surface, and then stems fall over in response to a physical force, such as wind, snow, or wildlife traffic. Even when stems fall months after harvest, they provide similar surface cover as would have been provided immediately after harvest. Standing stem dimensions do not change greatly, although

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Abbreviations: A , empirical constant in TC calculation; B , threshold decomposition days required for stem number decline; DAH, days after harvest; DD, decomposition day; k , decomposition rate constant; MC, moisture coefficient; P , daily precipitation; PC, precipitation coefficient; SF, standing stem fraction, relative to initial stem number; T , daily average temperature; TC, temperature coefficient; T_{opt} , optimum T ; WEPP, Water Erosion Prediction Project.

considerable mass is lost by leaching. Crop residues distributed flat on the soil surface at the time of harvest would have undergone significant mass loss, and probably cover loss, by the time the stems fall.

Decomposition of the stem base is controlled by temperature and moisture, similarly to flat surface residue decomposition (Steiner and Tanaka, 1990). Residue composition or quality, and possibly soil N, are also important. Objectives of this study were to develop a simple species- and climate-based equation for predicting standing stem number decline over time and to evaluate its performance in different climatic regimes.

MATERIALS AND METHODS

Bushland Field Experiment

Stem number over time was monitored for 'TAM-107'¹ winter wheat, 'Oslo' spring wheat, 'Post' winter barley, and 'Lew' spring oat near Bushland, TX. Crops were grown on a Pullman clay loam in 0.25-m rows, oriented north-south. Twelve main plots were 12 by 70 m, arranged in three randomized complete blocks of four crop treatments. High, medium, and low initial stem densities were obtained for each crop by differentially managing seeding rate, fertilizer, and growing season irrigation (Table 1).

Each main plot was split into three density subplots before planting. The high, medium, and low density treatments were in the north, center, and south one-third of each main plot, respectively. Density treatments were applied in strips, to minimize irrigation pipe and time required to irrigate level-border plots. The low density treatment received establishment irrigation (13 December for fall-sown crops and 2 April for spring-sown crops). The high density treatment was irrigated when $\approx 50\%$ of plant available water was depleted, as determined by neutron probe readings from access tubes centered in each subplot (10 December for fall-sown crops and 18 March, 12 April, and 2 May for all crops). The medium density treatment was irrigated on 12 December (fall-sown crops), 5 April, and 14 May. In some cases, treatments intended to produce high initial stem density did not tiller as much as the medium level. However, we obtained a range of initial stem numbers for each crop.

Following harvest, each crop-density subplot was split into thirds for fallow period irrigation treatments consisting of dryland, full irrigation, and alternate date irrigation. Fallow irrigation treatments were randomly assigned to sub-subplots. The full irrigation treatment was irrigated to maintain a moist surface (as often as weekly) with the minimum amount of water (≈ 50 mm) required to flow across the 12- by 22-m sub-subplot. Irrigation was not applied when daily mean air temperature was at or near freezing.

A stem count area (0.375 m^2) of 0.5 m length of three adjacent rows was established in a controlled traffic area of each sub-subplot. Initial counts of standing stems were made on 19 July 1991 (18 DAH) and additional counts were made on 98, 158, 223, 289, and 379 DAH. Handheld inventory counters were used to make counts, and stems that were $> 10^\circ$ from horizontal by visual assessment were counted as standing. Stem numbers for each plot and date were normalized as fraction (0 to 1) of the initial stem number for that plot.

Rainfall was measured in a standard weather service rain gauge ≈ 50 m east of the experimental area. Daily mean, maximum, and minimum air temperatures at 2 m above a grass surface were measured either at the experimental area or at a

Table 1. Growing season treatments used to produce the small-grain stem number decomposition plots at Bushland, TX.

Crop and density†	Seeding rate	Fertilizer		Irrigation	Stem number
		N	P		
		kg ha ⁻¹			
Winter wheat					
High	112	135	168	435	1056
Medium	84	55	168	335	710
Low	67	0	168	95	720
Spring wheat					
High	112	135	168	320	464
Medium	84	55	168	235	430
Low	67	0	168	95	225
Winter Barley					
High	112	135	168	435	693
Medium	84	55	168	335	755
Low	67	0	168	95	385
Spring Oat					
High	112	135	168	320	429
Medium	84	55	168	235	718
Low	67	0	168	95	307

† High and medium, and low density treatments were applied to produce a range of harvest stem densities for each species.

Class A weather station located 1 km east of the experimental site.

Calculating Decomposition Days

For standing stem decomposition, precipitation (P , in mm) and air temperature (T , in $^\circ\text{C}$) were chosen as appropriate climate parameters to normalize the climatic effect over time. The decomposition days (DDs) were accumulated based on the daily minimum of the moisture or temperature coefficient. Each coefficient was constrained from 0 to 1, with 1 indicating optimum conditions for microbial activity and 0 indicating no microbial activity. A daily precipitation coefficient (PC) was calculated as follows:

$$\begin{aligned} \text{If } P \geq 4, \quad PC &= 1.0 & [1a] \\ \text{If } P < 4, \quad PC &= P/4 & [1b] \end{aligned}$$

The value of 4 mm that Stott et al. (1988) used as a threshold for residue water-holding capacity is adequate to fully wet even dense layers of surface residues and moisten the underlying soil surface. Smaller amounts are intercepted by the residue layer and dry relatively quickly. Heilman et al. (1992) showed that wheat residue water content decreases gradually over several days following an irrigation. To approximate this effect, we allowed each precipitation event to influence the moisture coefficient (MC) over several days, with the subscript t representing the current day, as follows:

$$MC_t = 0.5 MC_{t-1} + PC_t \quad [2]$$

with MC_t constrained to remaining ≤ 1.0 .

The temperature coefficient (TC) was calculated after Stroo et al. (1989), using the daily average air temperature as T :

$$TC = \frac{2(T + A)^2 (T_{\text{opt}} + A)^2 - (T + A)^4}{(T_{\text{opt}} + A)^4} \quad [3]$$

where $T_{\text{opt}} = 32^\circ\text{C}$, and $A = 0$. Stroo et al. (1989) used $A = 6.1$ to analyze crop residue decomposition in both laboratory and field conditions, but this results in the equation going to 0 at $T = -6.1^\circ\text{C}$. The equation must be constrained to

¹ Reference to a trade or company name is for specific information only and does not imply approval or recommendation of the company by USDA to the exclusion of others that may be suitable.

remain at 0 when $T < A$; otherwise, it increases with decreasing low temperatures.

Daily DD was set equal to the minimum of TC and MC for that day. Daily DDs were then accumulated to normalize the time scale to environmental conditions. Stem fraction (SF = stem no. /initial stem no.) decline was described as an exponential function of DD:

$$SF = \exp [k(DD - B)] \quad [4]$$

where k is the decomposition rate constant (DD^{-1}) and B is a threshold number of DDs required to decompose the stem base. Regression coefficients, k and B , were fit by pooling all density and fallow irrigation plots for a given crop and using the MODEL procedure in SAS (1988).

Evaluating Stem Number Prediction

Independent measurements were taken from 1989 to 1992 in barley and spring wheat stubble near Mandan, ND, and in spring and winter wheat stubble in eastern Oregon (Echo and Pendleton) and in winter wheat stubble near Bushland, TX, to evaluate the generality of our equations for predicting stem number persistence (Table 2). In North Dakota and Oregon, six plots (1 m²) were established in no-tillage fields in controlled traffic areas. At Bushland, counts were made in 0.5-m² areas in the wettest and driest plots of a line-source irrigation decomposition study and in 1-m² areas in high-residue wheat stubble in an evaporation study. Daily precipitation and

Table 2. Experiments conducted to evaluate the stem number equation derived at Bushland, TX.

Crop and cultivar	Harvest date	Sampling dates	Weather station
d after harvest			
Mandan, ND (47° N, 101° W; 520 m elev.)			
Barley 'Bowman'	8 Aug. 1989	17, 125, 244, 303, 339, 378, 447, 631	Mandan, ND USDA-ARS
Spring wheat 'Marshall'	8 Aug. 1989	17, 125, 244, 303, 339, 378, 447, 631	
Echo, OR (45° N, 121° W; 570 m elev.)†			
Winter wheat 'Stephens'	1 Aug. 1989	11, 45, 65, 94, 129, 171, 234, 259, 322, 346, 382, 410, 435, 535, 627, 708, 744, 793	Moro, OR NWS‡
Spring wheat 'Pioneer 881'	10 Aug. 1989	2, 36, 56, 85, 120, 162, 225, 250, 313, 337, 373, 401, 426, 526, 618, 699, 735, 784	
Pendleton, OR (46° N, 119° W; 450 m elev.)†			
Winter wheat 'Stephens'	2 Aug. 1989	10, 44, 64, 93, 128, 170, 233, 258, 321, 345, 381, 409, 434, 534, 626, 707, 743, 792	Pendleton, OR USDA-ARS
Spring wheat 'Dirkwin'	9 Aug. 1989	3, 37, 57, 86, 121, 163, 226, 251, 314, 338, 374, 402, 427, 527, 619, 700, 736, 785	
Bushland, TX (35° N, 102° W; 1170 m elev.)			
Winter wheat 'TAM-107'	7 July 1992	113, 209	Bushland, TX USDA-ARS
Winter wheat 'TAM-105'	25 June 1990	59, 94, 130, 156, 215, 274, 316, 347	

† Stems at Echo and Pendleton were counted on the same calendar days, but different days after harvest.

‡ NWS, National Weather Service.

maximum and minimum air temperature were obtained from the nearest USDA-ARS or National Weather Service station. Wheat crops at Bushland and Mandan were hard red wheat, as was the wheat used to develop the equations. The wheat types in eastern Oregon were soft white wheat, except the Pioneer 881 spring wheat at Echo, which was a durum wheat. Stem counts were normalized to fraction of initial count for each plot, and cumulative DDs from harvest were calculated for each field as described above.

Stem number over time was predicted for each field using local cumulative DDs since harvest and crop-specific decomposition equations derived from the Bushland experiment. Predicted and measured stem fraction remaining were compared using linear regression and the paired t -test.

RESULTS AND DISCUSSION

Winter wheat stem fraction remaining on a given day (Fig. 1) was highly variable at Bushland, depending on climatic conditions that prevailed during a time interval. Stem fraction remaining ranged from 0.62 to 0.15 by 158 DAH, depending on the decomposition environment. The USDA Water Erosion Prediction Project (WEPP) (Arnold et al., 1991) assumes a 1% decline of standing stems per day, starting with harvest date, which is clearly not realistic (Fig. 1). By 17 DAH, the WEPP model would predict a standing stem fraction of 0.83, although we found no evidence of stem number decline at this count. No clear initial stem density effect was seen; therefore, counts from all density treatments were pooled for analysis of the DD effect.

Decomposition days at Bushland were limited by moisture at some times of the year and by temperature at others (Fig. 2), as shown by the slower increase of cumulative DDs (daily minimum of TC and MC) compared with either cumulative MC or TC. Because the daily mean temperature was never as high as optimum (32° C), TC limited the DD accumulation to <1.0 on precipitation days. In winter (from about 150 to 250 DAH), TC was the predominant limitation, as seen by the flatness of the DD curve compared with the increase in the MC curve, although small DD accumulations occurred with precipitation events during the relatively mild winters. Decomposition days for fallow-period irrigation treatments (Fig. 3) show the variability in DD accumu-

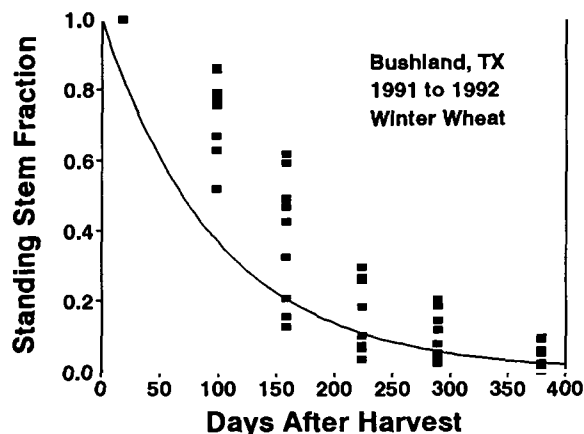


Fig. 1. Decrease in standing winter wheat stems (fraction of initial) during fallow. Each point is the mean of three replicate measurements. The line represents WEPP predicted stem fraction over time.

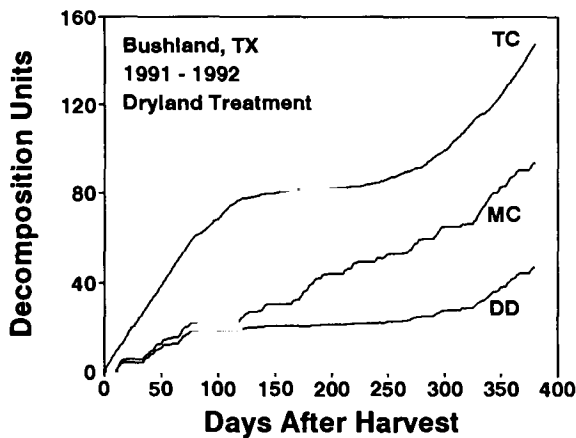


Fig. 2. Cumulative temperature (TC) and moisture (MC) coefficients and decomposition days (DD, daily minimum of TC or MC) following small-grain harvest at Bushland, TX, 1991 and 1992.

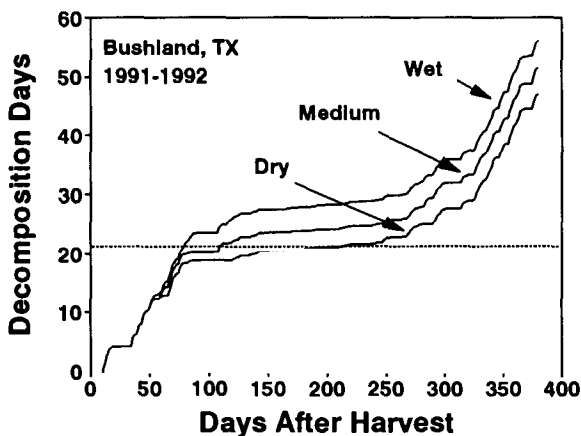


Fig. 3. Cumulative decomposition days following small-grain harvest for fallow-period irrigation treatments at Bushland, TX, 1991 and 1992.

lation. For example, 21 DD had accumulated by 79 DAH on the wettest treatment, but this number was not accumulated until 190 DAH on the dry treatment.

Stem fraction remaining was clearly related to DDs (Fig. 4). Coefficients for winter wheat, spring wheat, winter barley, and spring oat for Eq. [4] are given in Table 3. Threshold DDs required before stems started falling (B) were similar across species; however, oat stems decomposed and fell quickly, compared with the other crops, while spring wheat persisted longest (Fig. 5). A high percentage of stems fell between 17 and 30 DD, but many months were required to accumulate these DDs. This equation form is similar to that commonly used for mass loss from residues, with the exception that mass loss begins immediately, without a threshold requirement. Under constant laboratory conditions, calendar days are used as the time scale.

Stem persistence prediction was evaluated using North Dakota, eastern Oregon, and Texas data. Stem fraction over time for the three regions was compared with the WEPP prediction (Fig. 6). The need to normalize the time scale for the different decomposition environments is clear. Decomposition day accumulation was slow in

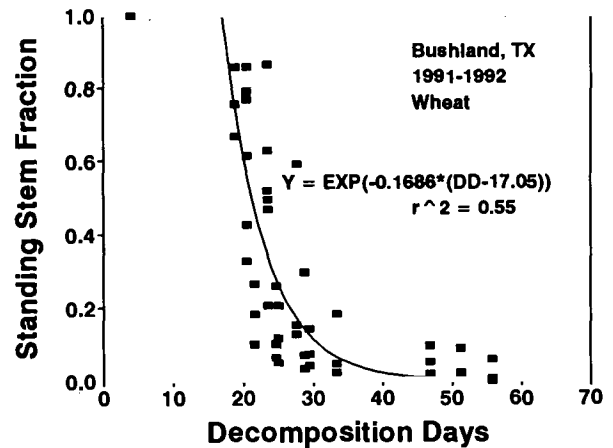


Fig. 4. Exponential relationship of winter wheat stems (fraction of initial) and decomposition days at Bushland, TX, 1991 and 1992. Points represent the mean of a density-moisture treatment.

Table 3. Regression coefficients of the exponential decay equation for standing stem fraction† for four small-grain crops at Bushland, TX, 1990 to 1991.

Crop	k	B	r^2
Winter wheat	-0.169	17.05	0.55
Spring wheat	-0.116	17.75	0.62
Barley	-0.176	17.26	0.65
Oat	-0.284	17.56	0.65

† SF = $\exp k(DD - B)$. The criteria for convergence was $P \leq 0.001$.

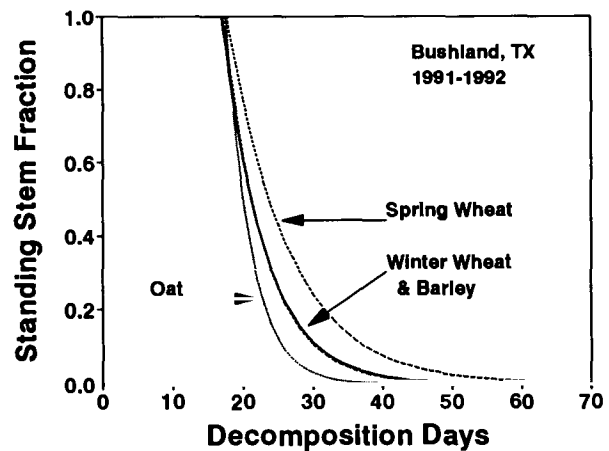


Fig. 5. Exponential decline of stem number (fraction of initial) for four small-grain crops. (See Table 3 for equation coefficients).

Oregon and North Dakota, compared with Bushland (Fig. 7). At Bushland, the threshold of 17.5 DD had accumulated by 76 DAH, but it required 302 d at Pendleton and 326 d at Mandan to reach the threshold. Accumulation was relatively continuous in eastern Oregon, where winter precipitation predominates, compared with Great Plains locations with predominately summer precipitation and cold, dry winters. Summer DD accumulation was similar at Mandan and Bushland, but winter, with almost no DD accumulation, was much longer at Mandan than at Bushland.

Initial tests of the generality of DDs across locations

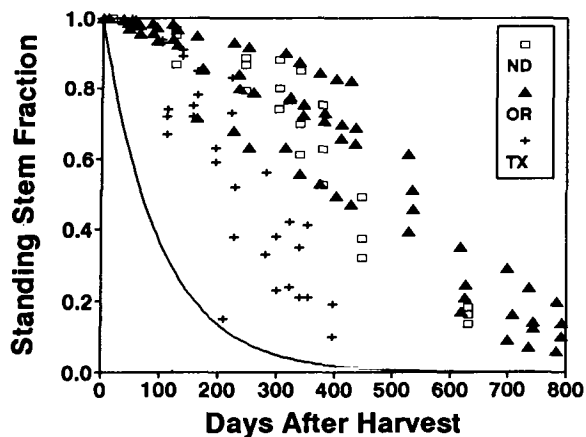


Fig. 6. Standing stem fraction of small-grain stems (winter wheat, spring wheat, and barley) from three regions over time compared with WEPP stem fraction predictions (line).

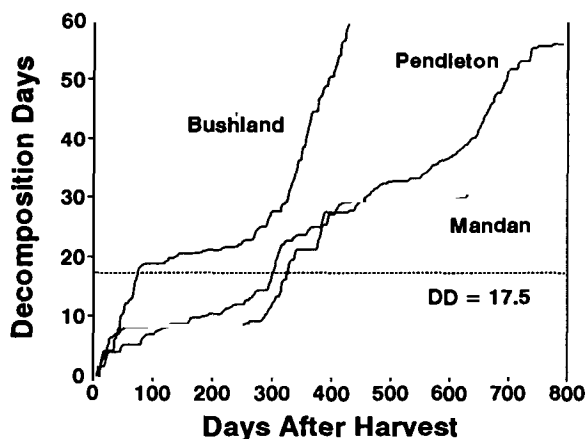


Fig. 7. Accumulation of decomposition days following harvest of small grains at Bushland, TX (dryland fallow period); Mandan, ND; and Pendleton, OR.

showed that predicted stem fraction compared reasonably well with measured values for winter wheat, spring wheat, and barley (Fig. 8). While predictions are not perfect, paired *t*-tests indicate no significant difference between predicted and measured values for barley or spring wheat. However, there was a mean deviation of 0.16 for winter wheat averaged across Oregon and Texas data (Table 4).

At both Oregon and North Dakota, a small fraction of stems (10–20%) fell over before the threshold of ≈ 17.5 DD accumulated; it took nearly a year to reach this threshold value. The stems may have fallen due to more time for physical disturbance of the plots (e.g., heavy snow, high winds, wild animal traffic). In eastern Oregon, predicted stem fraction remaining was 1.0 for the first eight sampling dates (through ≈ 260 DAH), but measured values averaged 0.9 for both crops across locations.

After the threshold DD, stem numbers were predicted very well at Mandan and reasonably well at Echo. Stem numbers declined more slowly than predicted at the eastern Oregon sites, except for the durum spring wheat at Echo. Different decomposition coefficients may be needed for different types of wheat.

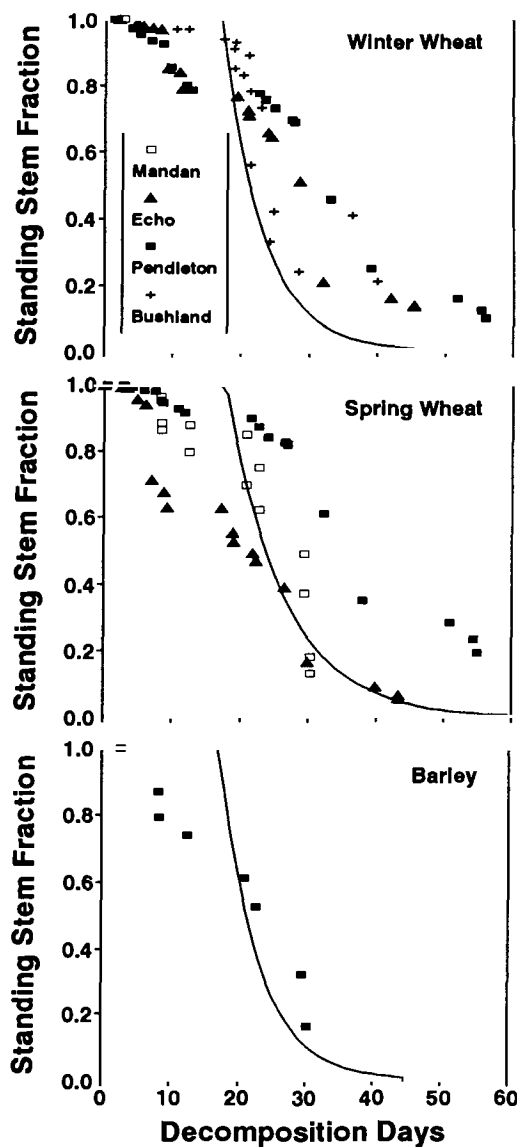


Fig. 8. Standing stems remaining (fraction of initial) of winter wheat, spring wheat, and barley. Each point represents the treatment mean. The lines represent stem number predicted using equations developed at Bushland, TX (Table 3).

Stem number predictions were better at Echo than at Pendleton late in the fallow period. Stem number decline was more rapid at Echo, even though it is a drier site and accumulated fewer DDs. The Pendleton soil had 20 g kg^{-1} organic matter, compared with 14 g kg^{-1} at Echo, and both soils were silt loams, so soil differences are probably not associated with the different persistence of stems. A large stem number decline at Echo was associated with strong winds and blowing weeds from an adjacent field prior to counts on 22 Mar. 1990 (8.78 DD for spring wheat). While the stems at Pendleton were leaning following this windstorm, there were no blowing weeds, and more stems were still standing. This is consistent with the two-step nature of the process: first, the stem base has to decay; second, a physical force is required to cause the stems to fall. The more decomposed the base, the less physical force is required. (This characteristic is not considered in our model.)

Table 4. Paired *t*-test of the difference between measured and predicted stem fraction across observation dates.

Location and crop	Mean difference	<i>t</i>	Probability
Mandan, ND			
Barley	-0.016	-0.52	0.61
Spring wheat	-0.002	-0.08	0.93
Eastern Oregon			
Winter wheat	0.121	7.23	0.0001
Spring wheat	0.019	1.04	0.30
Bushland, TX			
Winter wheat	0.207	11.07	0.0001
Data pooled across locations			
Spring wheat	0.013	0.94	0.35
Winter wheat	0.163	12.84	0.0001
Data pooled across locations and crops			
All crops	0.094	9.95	0.0001

Linear regressions of predicted on measured stem fraction generally resulted in insignificant intercepts and slopes near 1.0 (Table 5). Negative intercepts and slopes > 1.0 for barley at Mandan and winter wheat in Oregon resulted from the previously discussed initial decline in stem numbers prior to accumulation of the threshold DDs.

CONCLUSIONS

Decomposition days based on precipitation and daily average temperature indices appear promising for predicting persistence of standing stems across diverse climates. Additional testing is needed over a broader range of climates, including more humid environments, and for crops other than small grains. It is possible that decomposition coefficients *k* and *B* (Eq. [4]) can be related to stem chemical and physical characteristics; however, evaluations need to be made for a broader range of crops. Additional research is also needed to develop a simple quantitative index of the forces that act upon the stems.

Decomposition days described in this paper are similar in concept to decomposition units used for predicting residue mass loss (Stroo et al., 1989; Stott et al., 1990; Arnold et al., 1991). The difference is that precipitation (instead of soil water content) was used to calculate the moisture coefficient, and a threshold is required before stems fall. This study indicates that residue decomposition models can be modified to deal with the standing stem component of the residues and the transition of mass from standing to flat orientation.

Generally, standing and flat residues are not explicitly dealt with in estimating residue effects on biological and micrometeorological processes. However, impacts of standing stems on wind speed profiles, radiation balance, and shading at the soil surface are very different from flat residue impacts. Additionally, standing residues persist longer than a comparable amount of flat surface residue. Improved understanding of persistence and decomposition of standing stems should improve wind

Table 5. Coefficients of linear regressions[†] of predicted on measured stem fraction. Predicted values used equations developed at Bushland, TX and local decomposition days.

Location and crop	<i>a</i>	<i>b</i>	CV	<i>r</i> ²
Mandan, ND				
Barley	-0.162*	1.309	30.6	0.78**
Spring wheat	0.0	1.0	25.0	0.73***
Eastern Oregon				
Winter wheat	-0.214***	1.146	45.1	0.69***
Spring wheat	0.0	0.966	40.8	0.59***
Bushland, TX				
Winter wheat	0.0	0.670	48.4	0.42***
Data pooled across locations				
Winter wheat	-0.075**	0.865	50.3	0.55***
Spring wheat	0.0	0.976	36.5	0.62***
Data pooled across locations and crops				
All crops	0.0	0.864	45.5	0.56***

*, **, *** Probability at the 0.05, 0.01, or 0.001 levels for the hypothesis that *a* = 0 (*a* column) or that the linear regression is significant (*r*² column).

[†] $Y = a + bX$, where *Y* is predicted and *X* is measured stem fraction, *a* is the intercept, and *b* is the slope. When *a* was not significantly different from 0, the equation was restricted to a zero intercept.

erosion prediction, snow-trapping estimation, and may be of interest for a wide range of micrometeorological and energy balance studies.

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